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# Turbulence and Convection Parameterizations: the Eddy-Diffusivity/Mass-Flux (EDMF) Approach and its Implementation into the GFS Model

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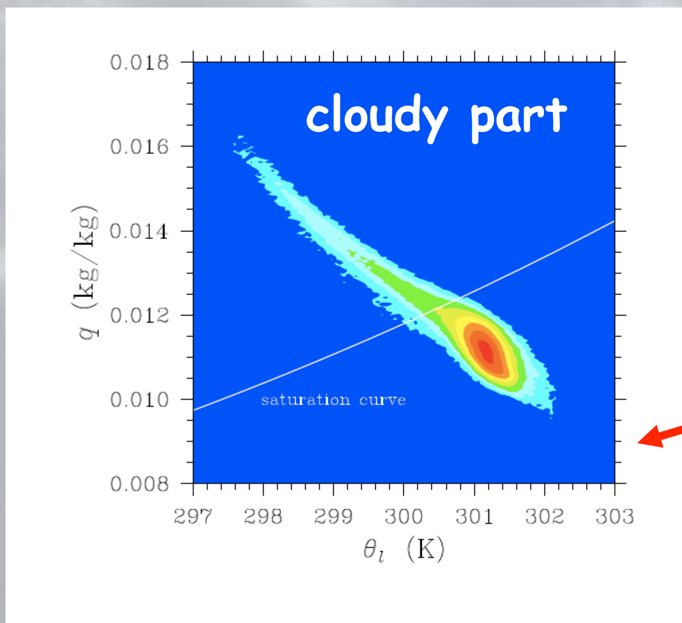
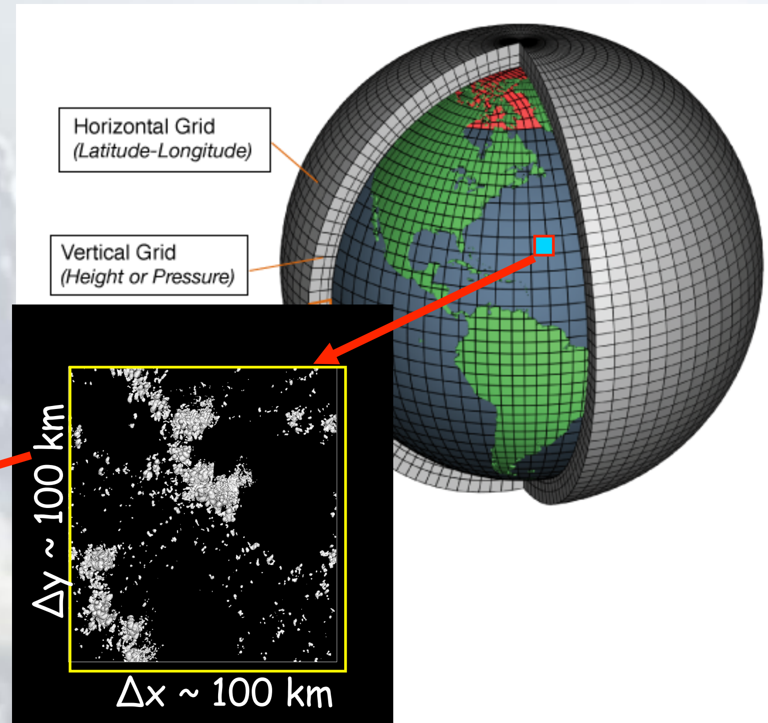
# Turbulence and Convection in Weather and Climate Models




$$\varphi = \bar{\varphi} + \varphi' \quad \rightarrow$$

$$\boxed{\frac{\partial \bar{\varphi}}{\partial t} + \frac{\partial}{\partial x}\left(\bar{u}\bar{\varphi}\right) + \frac{\partial}{\partial y}\left(\bar{v}\bar{\varphi}\right) + \frac{\partial}{\partial z}\left(\bar{w}\bar{\varphi}\right) = -\frac{\partial}{\partial z}\left(\overline{w'\varphi'}\right) + \bar{S},}$$

Key issue: Turbulence and convection parameterizations

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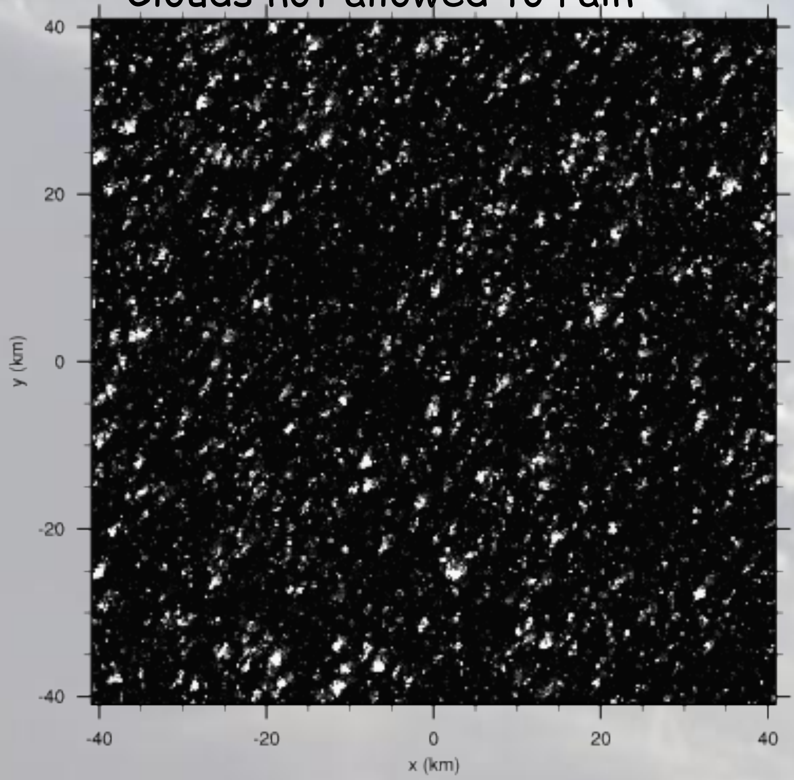
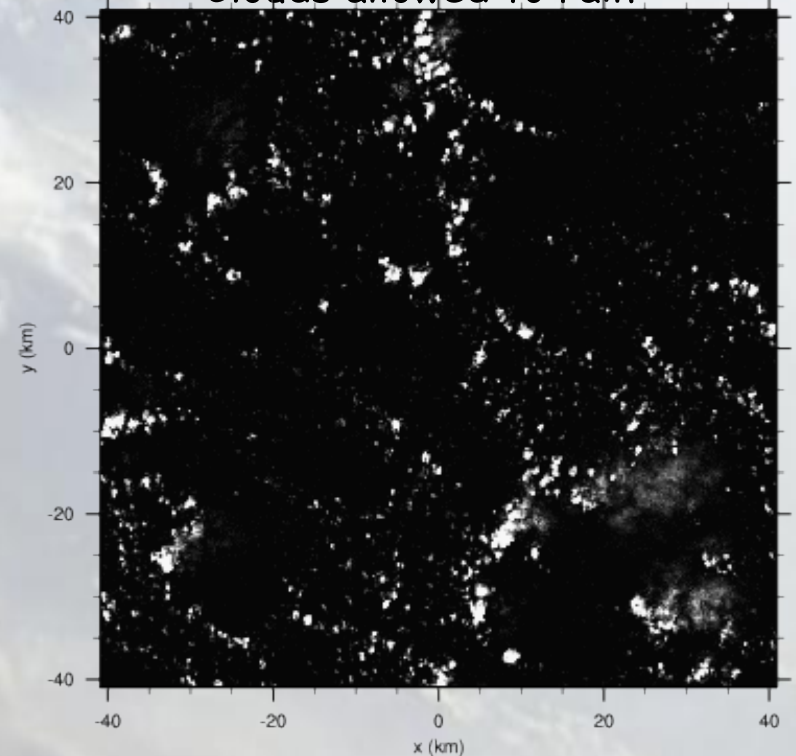
# Large-Eddy Simulation (LES) models

- LES models solve filtered version of Navier-Stokes equations
- High-resolutions (~ 10-100m) in all 3 dimensions
- LES models resolve most of the essential turbulence/convection
- Closures still needed for scales < 10m (but simpler to do)

Clouds not allowed to rain




Clouds allowed to rain




Matheou et al., MWR, 2011

# Clear and Cloudy Convective Boundary layers: Need for Unified/Integrated Approaches

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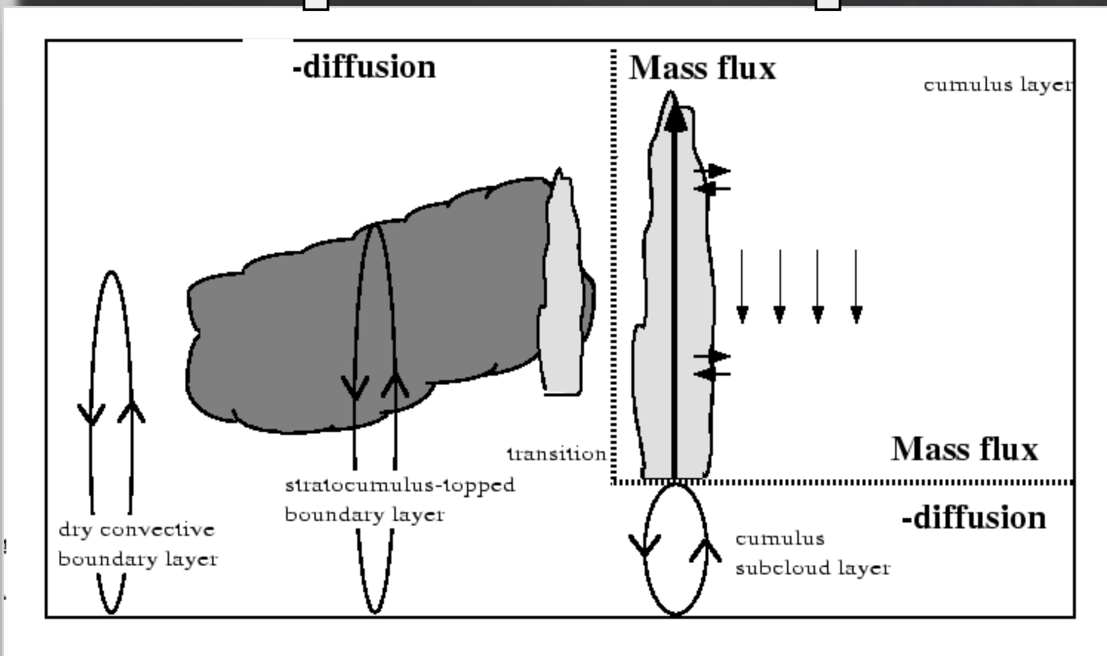
$$\overline{w'\phi'} \cong -K\frac{\partial\overline{\phi}}{\partial z}$$

$$\overline{w'\phi'} \cong M(\phi_u - \overline{\phi})$$

$$\frac{\partial\overline{\phi}}{\partial t} \cong -\frac{\partial}{\partial z}\left(\overline{w'\phi'}\right) + \overline{S}$$




Courtesy de Roode & Siebesma

Modularity leads to problems:

- "Double counting" of processes
- Interface problems
- Problems with transitions between different regimes

Key Problem: artificial modularity in vertical mixing parameterizations

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# Unified Approach: Eddy-Diffusivity/Mass-Flux (EDMF)

Dividing a grid square in two regions (updraft and environment) and using Reynolds decomposition and averaging leads to

$$\overline{w'\varphi'} = a_u \overline{w'\varphi'}_u + (1-a_u)\overline{w'\varphi'}_e + a_u(1-a_u)(w_u - w_e)(\varphi_u - \varphi_e)$$

where $a_u$ is the updraft area. Assuming $a_u \ll 1$ and $w_e \sim 0$ leads to

$$\overline{w'\varphi'} = \overline{w'\varphi'}_e + a_u w_u (\varphi_u - \overline{\varphi})$$

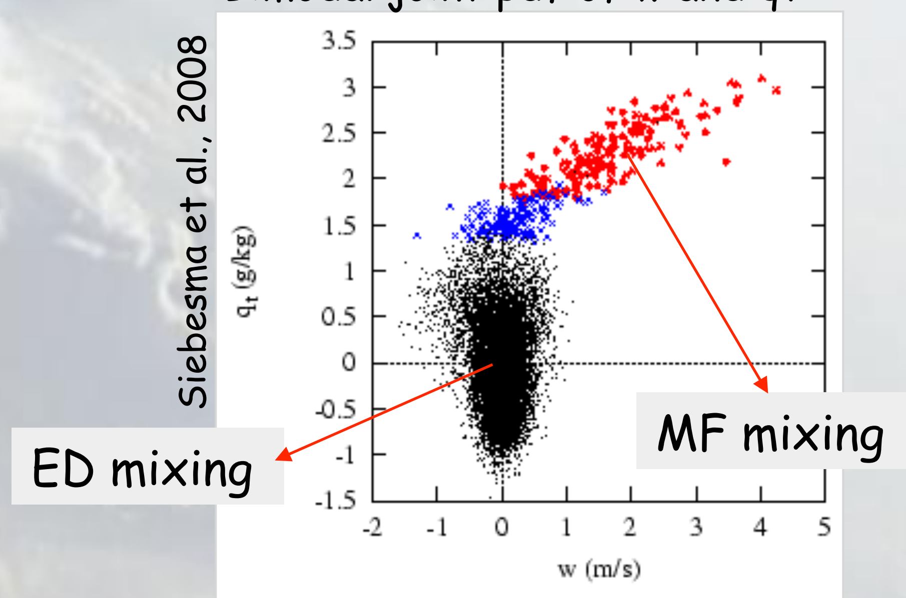
ED closure: assuming ED for 1st term and neglecting 2nd term

MF closure: neglecting 1st term and assuming $M = a_u w_u$

EDMF: $$\overline{w'\varphi'} = -k\frac{\partial \overline{\varphi}}{\partial z} + M(\varphi_u - \overline{\varphi})$$

Siebesma & Teixeira, 2000

Bimodal joint pdf of w and qt




EDMF represents turbulence/convection in an integrated manner

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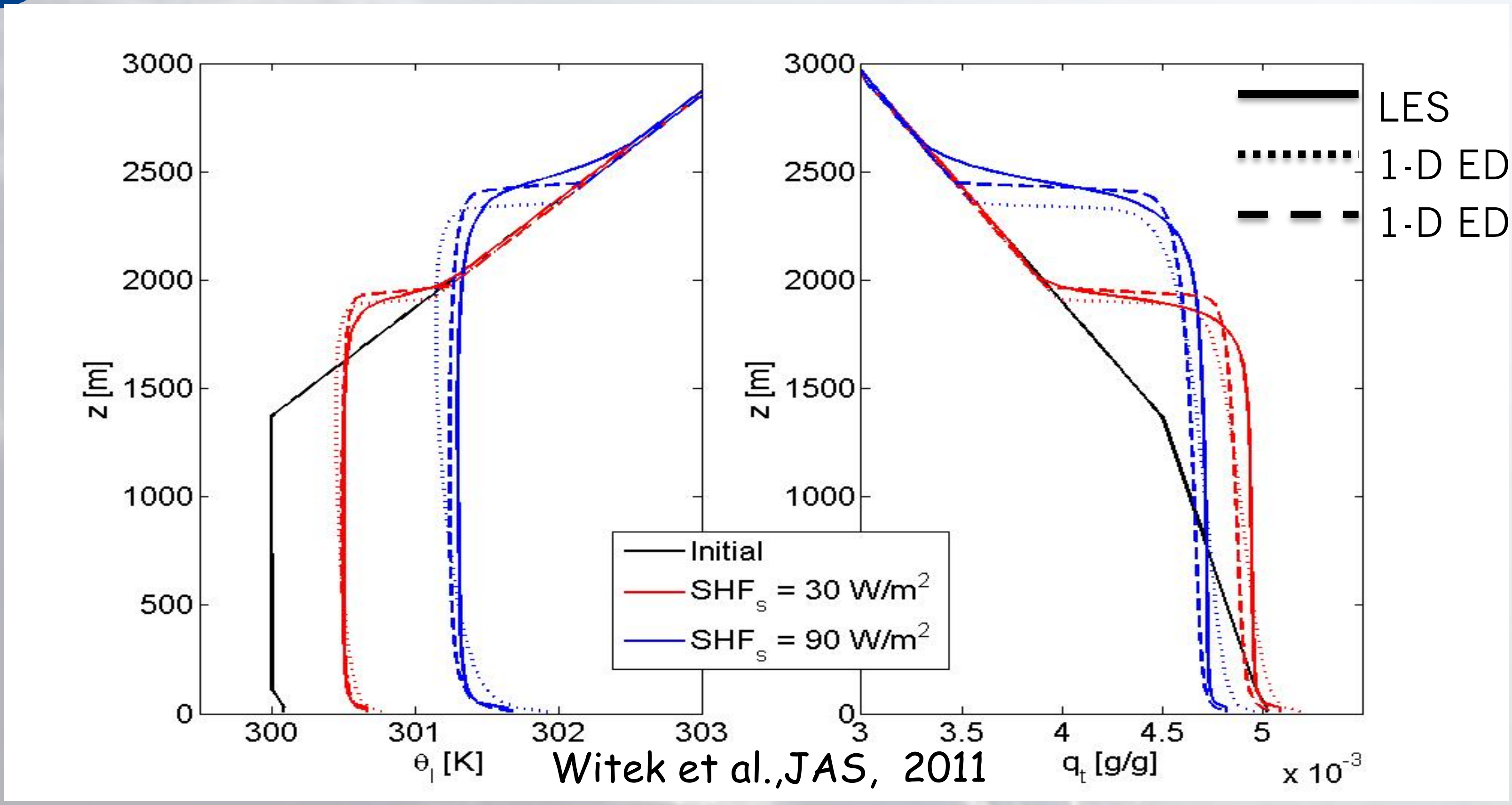
# Dry Convective Boundary Layer: θ and $q_t$ vertical profiles after 6 hours




Dry EDMF simulations:

- surface layer more realistic
- neutral profile in the well-mixed layer
- larger entrainment leads to better inversion height
- inversion layer too sharp compared to LES

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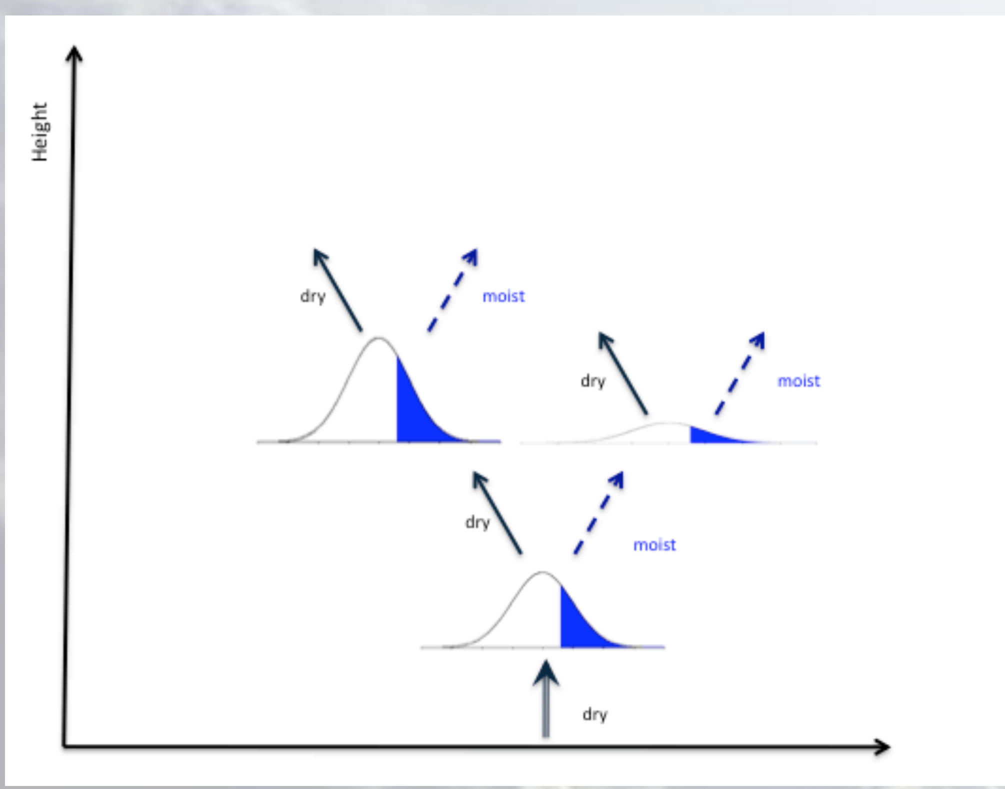
# Stochastic Plume for moist EDMF: using PDF of updraft properties




Suselj et al., JAS, 2012, 2013

1) Estimate PDF of plume/updraft properties (T, q, w)
2) Sample PDF to generate a variety of plumes (diff. properties)
3) Integrate different plumes in the vertical

Produces more realistic results than purely deterministic parameterization

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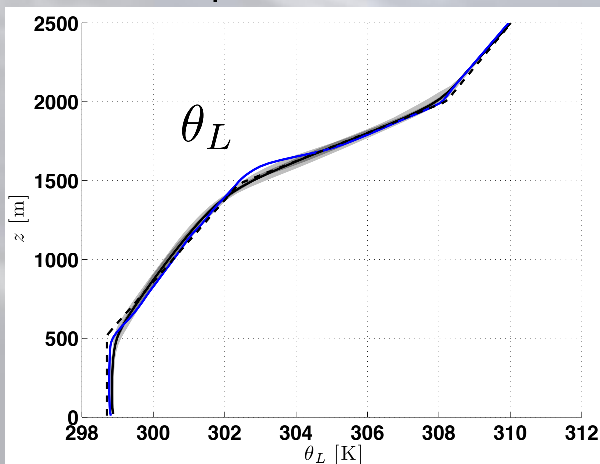
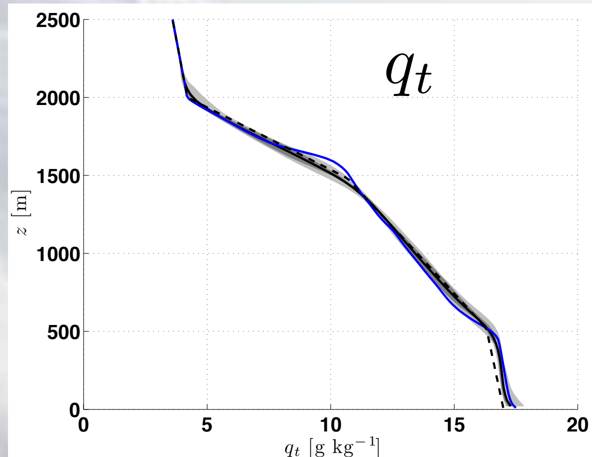
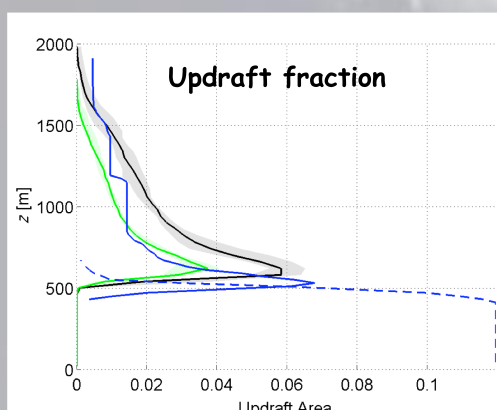
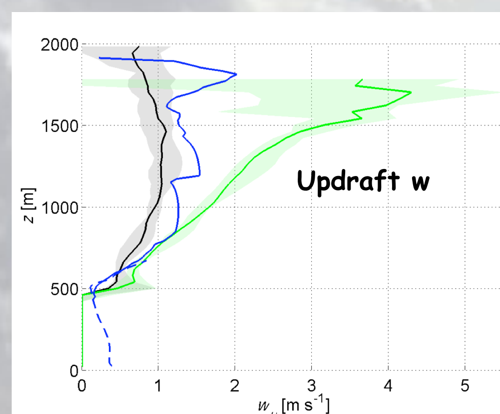
# EDMF simulation of shallow cumulus BOMEX case: comparison with LES

## Mean profiles between 3rd and 4th simulation hour




Suselj et al, JAS, 2012, 2013

New aspect: Using PDF of updraft properties

# Dry EDMF Implementation into GFS

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## Vertical diffusion equation

**Reference**

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left[K_c\left(\frac{\partial C}{\partial z} - \gamma_c\right)\right]$$

$$C \in (\theta, q_t, u, v)$$

$K$ - diffusion coefficient

$\gamma_c = b\frac{\overline{w'c'}^s}{w_s}$ - countergradient term

$w_s \equiv \left(u_*^3 + 0.7kw_*^3\right)^{1/3}$ - mixed-layer velocity scale

**EDMF**

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left[K_c\frac{\partial C}{\partial z} - M(C_u - C)\right]$$

$M = aw_u$ - mass-flux term

$C_u$ - updraft characteristics

$w_u(z), \theta_u(z), q_{t,u}(z)$ - unknown variables

$a \approx 0.1$ - fixed updraft fraction

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# Dry EDMF in GFS: SCM dry convection simulations

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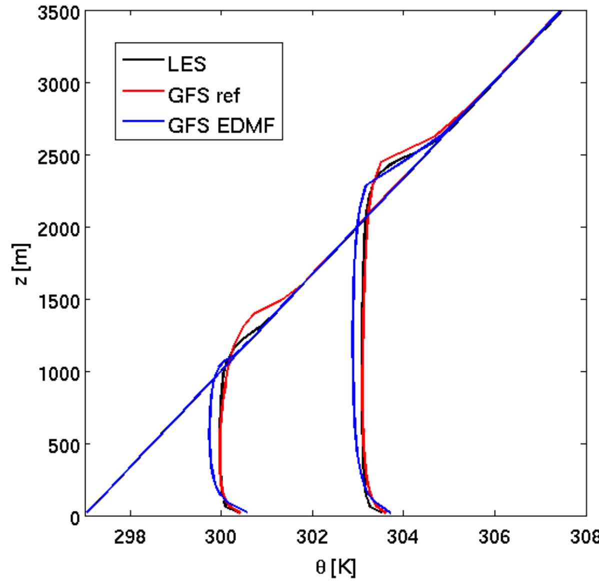
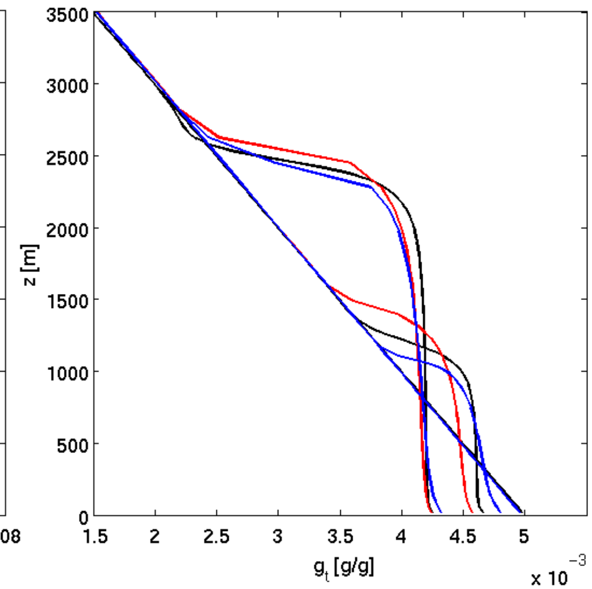
$SHF_s$=0.20

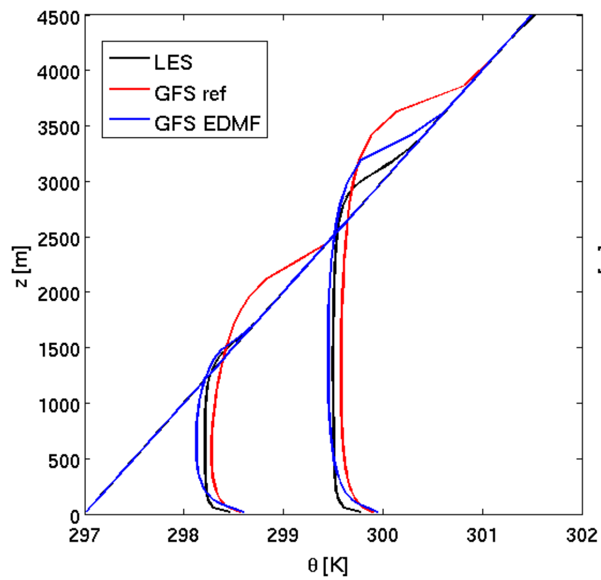
grad(θ)=3

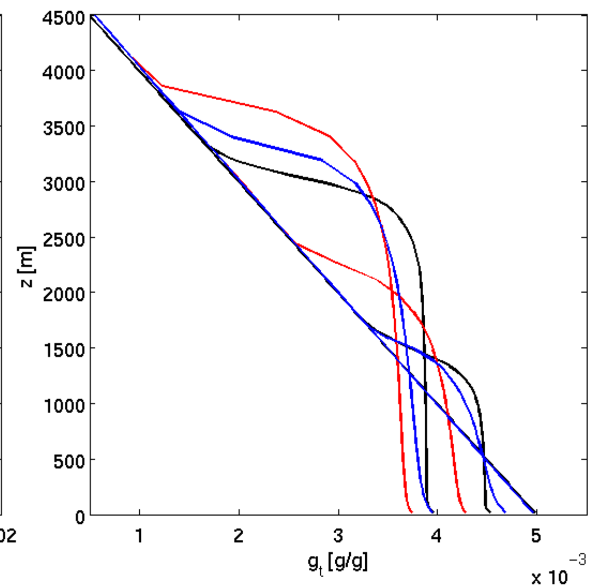



$SHF_s$=0.10

grad(θ)=1



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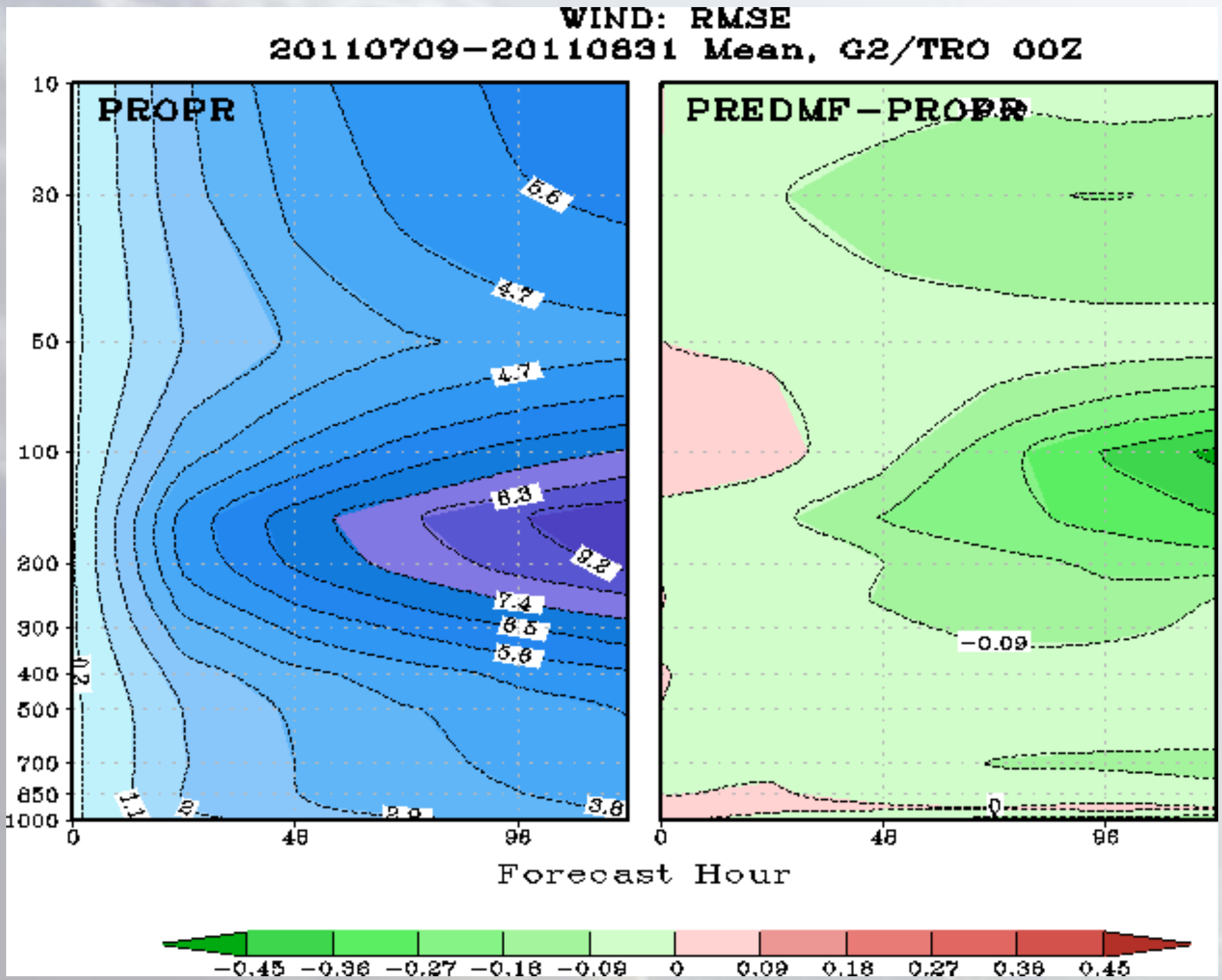
# 'Dry' EDMF Implemented into GFS: Data Assimilation experiments




- Neutral Z500 anomaly correlation, but significantly reduced wind errors

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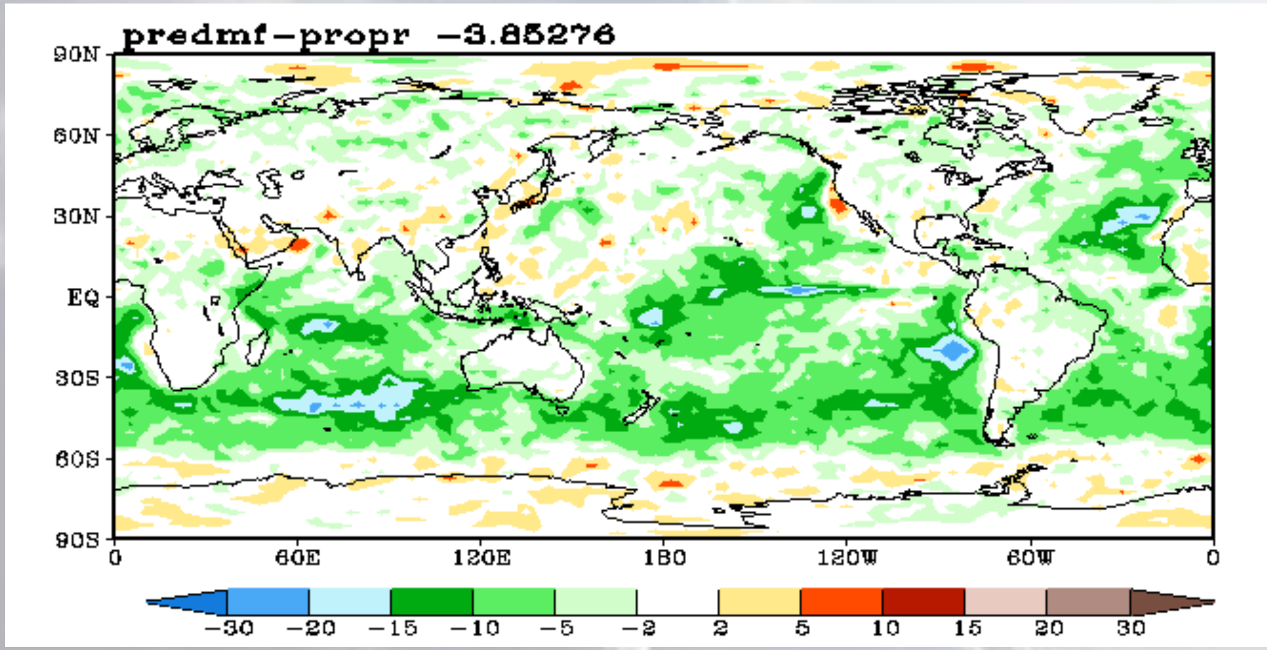
# Dry EDMF in GFS: Clouds

Dry EDMF decreases cloud cover in GFS by 4%




Dry EDMF is just an initial step to a fully moist implementation of EDMF proposed for Phase 2 of our CPT

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# Summary

- Realistic parameterization of PBL turbulence and convection is essential for weather and climate prediction
- Modularity problem in models: the need for unified schemes
- New approach: combining Eddy-Diffusivity and Mass-Flux (EDMF)
- Dry convection more realistic with EDMF
- Stochastic EDMF more realistic for moist convection
- Dry EDMF implemented in GFS: neutral Z500, less realistic clouds, substantial reduction of wind errors